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14. ABSTRACT

This presentation was to review our yearly progress.

15. SUBJECT TERMS

decision making, cortical network, neural decoding, brain-machine interface, neurally-informed model

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Report Title

Project Review Presentation (Sajda) July 2012

ABSTRACT

This presentation was to review our yearly progress.

ARO/ARL Site Visit

Paul Sajda

Laboratory for Intelligent Imaging and Neural Computing
Department of Biomedical Engineering
Columbia University

Agenda

9a	Welcome and Introductions	P. Sajda (Columbia)
9:15a	Overview of ARO Decision & Neuro-Sciences	J. Spoonmore (ARO)
9:30a	Overview of ARO/ARL Projects at Columbia University	P. Sajda (Columbia)
9:45a	ARO Project: *Cortical Networks Underlying Rapid Decision Making*	P. Sajda (Columbia)
10:30a	Break	
10:45a	ARL CTA Seedling Project: *Constructing Mutually-derived Situational Awareness via EEG-Informed Graph-based Transductive Inference*	D. Jangraw (Columbia)
11:30a	*Commercialization and Operational Transition of Cortically-coupled Computer Vision Systems*	P. Sajda (Columbia)
12:00p	Postdoctoral exchange between ARL TNB and Columbia: *Neural Markers of Experts and Novices: Extensions to Gunshot Localization*	J. Sherwin (Columbia/ARL)
12:30p	Lunch and Discussion	All
2p	Adjourn	

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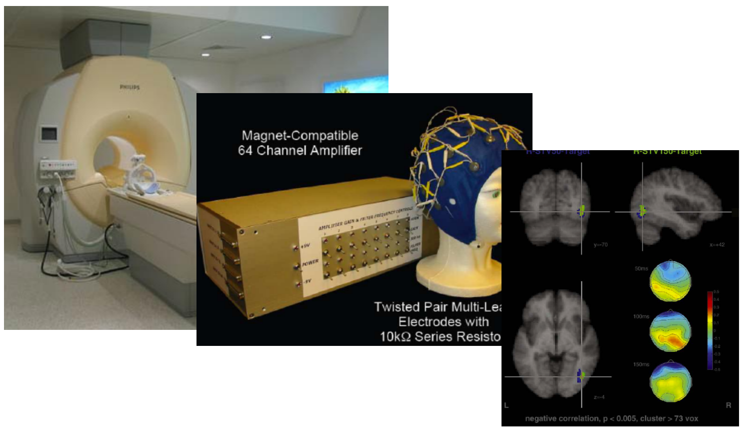
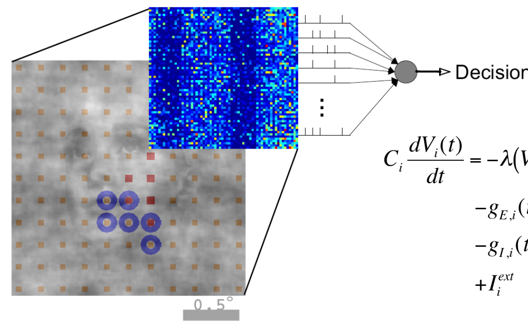
Laboratory for Intelligent Imaging and Neural Computing
LIINC

…using principles of reverse engineering to characterize the cortical networks underlying rapid decision making…

Measuring: Simultaneous EEG/fMRI

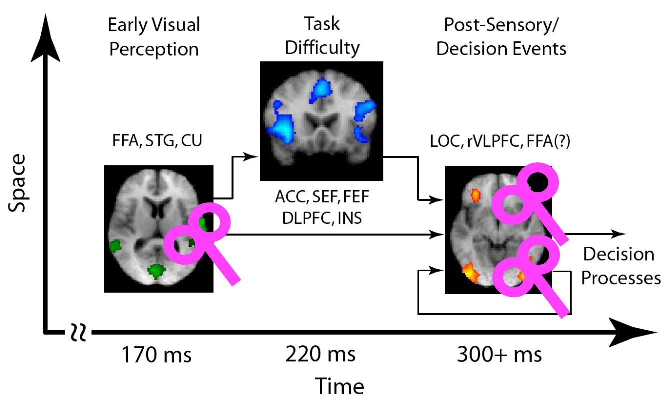


Modeling: Large Scale Neural Simulations

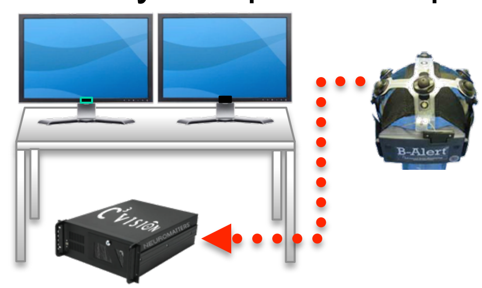


$$C_i \frac{dV_i(t)}{dt} = -\lambda\left(V_i(t) - V_L\right) - g_{E,i}(t,[S],\eta_E)\left(V_i(t) - V_E\right) - g_{I,i}(t,[S],\eta_I)\left(V_i(t) - V_I\right) + I_i^{ext}$$

Perturbing: High Resolution Informed TMS



Building: Cortically Coupled Computer Vision



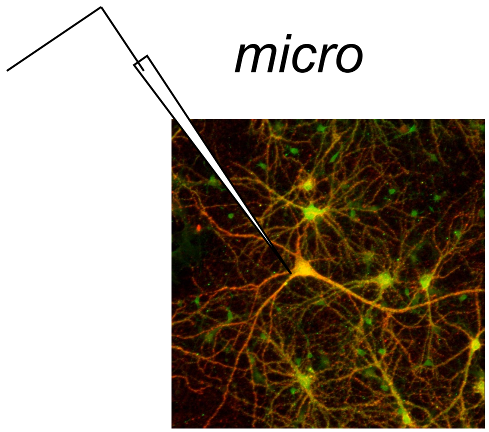
NEUROMATTERS™
neurotechnology research + development

ARO/ARL Projects

- **Cortical Networks Underlying Rapid Decision Making** (ARO)
- **Cortically-Coupled Computing: A Paradigm for Mutually-Derived Situational Awareness** (Seedling under ARL CTA)
- **Image Database and Neuroimaging Data Collection for Rapid Visual Decision Making** (ARL Technology Transition Project)

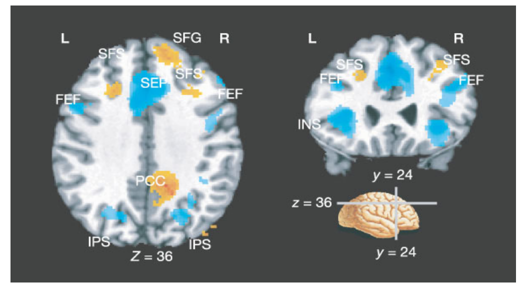
Cortical Networks Underlying Rapid Decision Making

micro



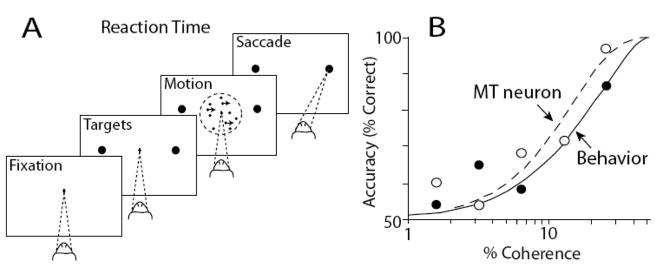
single neurons

macro

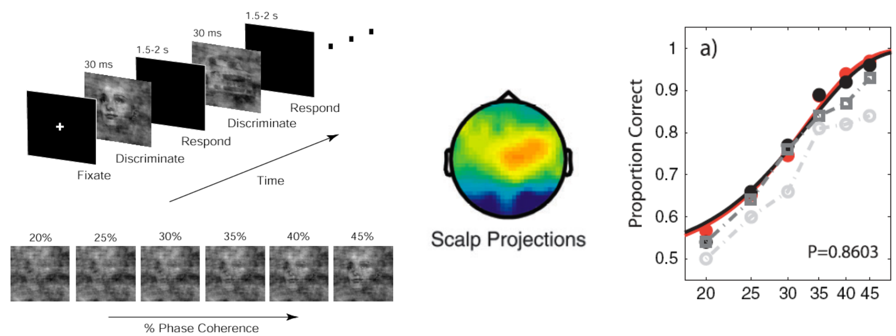


Heekeren et al., 2004

functional imaging



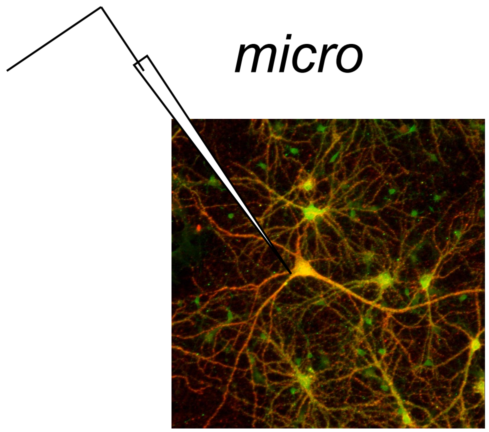
from Britten et al. 1992



from Philiastides & Sajda, 2006

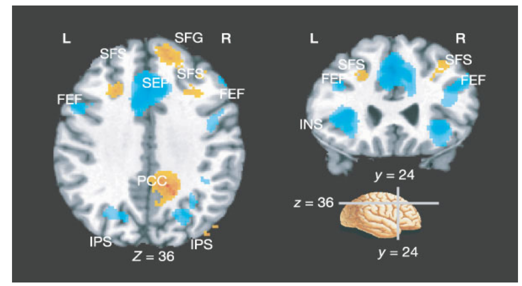
Cortical Networks Underlying Rapid Decision Making

micro



single neurons

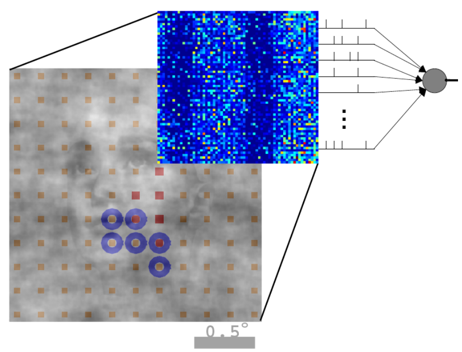
macro



Heekeren et al., 2004

functional imaging

meso



large populations

Cortical Networks Underlying Rapid Decision Making

Statement of Work

- Year 1:
  - Systematically design RSVP stimulus presentation paradigms and experiments for simultaneous EEG/fMRI
  - Run 5 subjects while simultaneously recording EEG and fMRI.
  - Analyze results in terms of spatial networks localized by integrating EEG and fMRI. Compare to dipole fits and rLoreta maps using EEG.
- Year 2:
  - Begin design of spatio-temporal (e.g. video) stimulus experiments which investigate integration of evidence across time
  - Manipulate difficulty of decision
  - Run 5 subjects while simultaneously recording EEG and fMRI.
  - Begin relating trial-to-trial variability to decision making models such as the drift diffusion models (of Ratcliff, 1978, 2009) and the bayesian decision models (of Beck, Ma et al, 2008.)
- Year 3:
  - Begin design of experiments for free-viewing search (eye-tracking).
  - Run 5 subjects while simultaneously recording EEG and fMRI.
  - Create a publicly available database of neural signatures of trial-to-trial variability, code for analyzing EEG/fMRI and code for neurally-informing decision models

Single-trial Analysis of Simultaneously Acquired fMRI and EEG

…a window into latent brain states…

Why Acquire EEG and fMRI Simultaneously?

- Electrical activity of the brain can be correlated with hemodynamic changes
  - Understanding neurovascular coupling
- High temporal resolution of EEG complements high spatial resolution of fMRI
  - fMRI seeding of EEG source localization
  - Correlating ERPs (trial-averages) with BOLD
- Single-trial variations in EEG, related to latent brain states (attentional shifting, cognitive load, decision evidence, memory encoding, etc.) can be correlated with hemodynamic activity.

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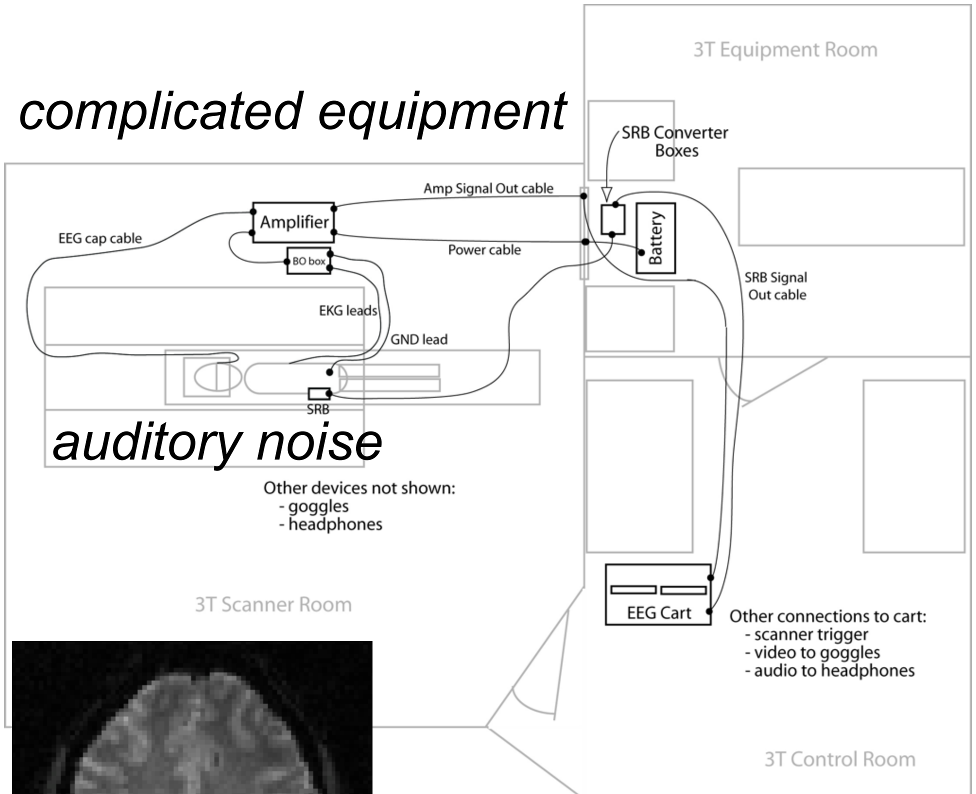
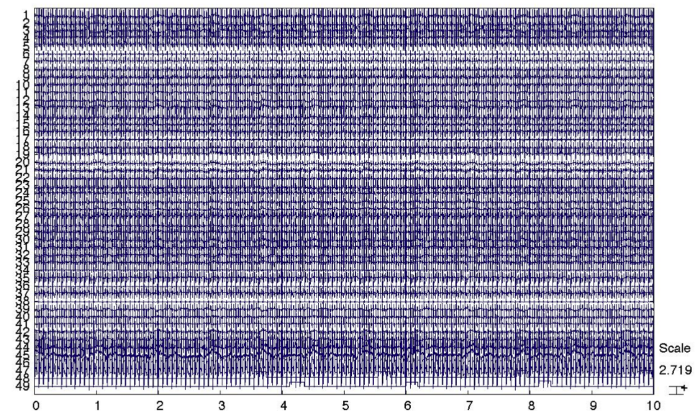
Challenges

complicated equipment

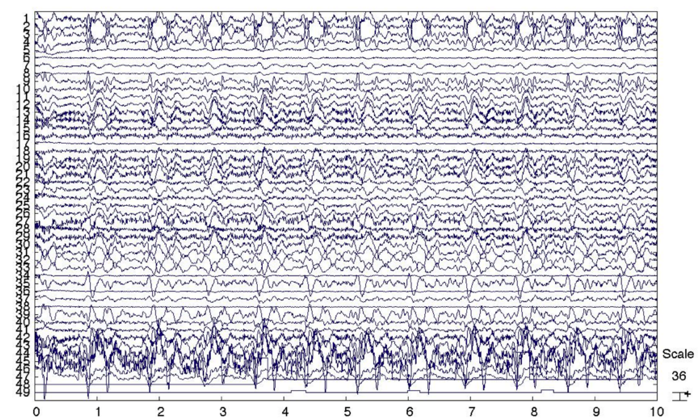


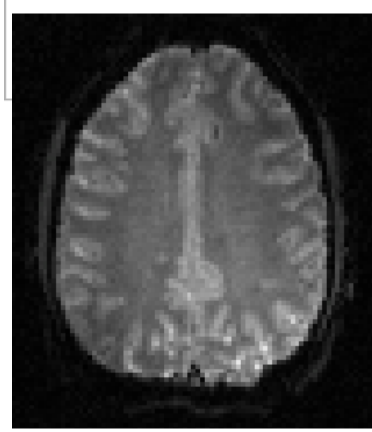
auditory noise

gradient artifact



BCG artifact

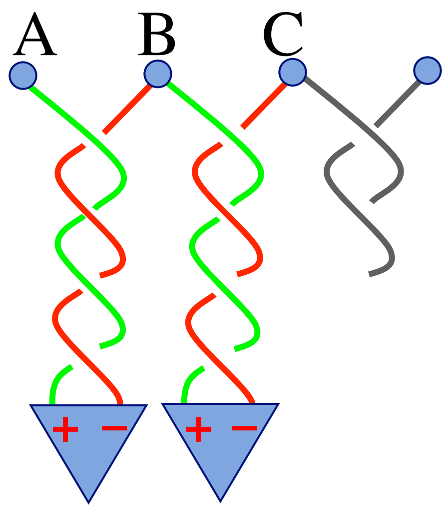


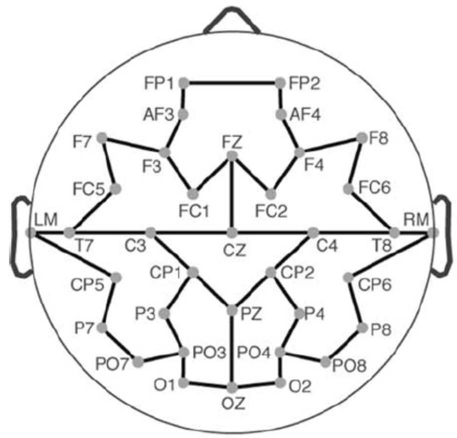


bias field

How to combine the data?

Our Solutions

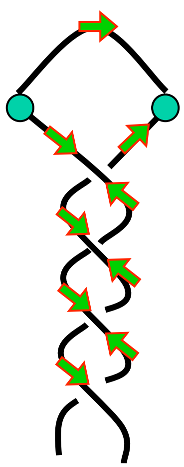


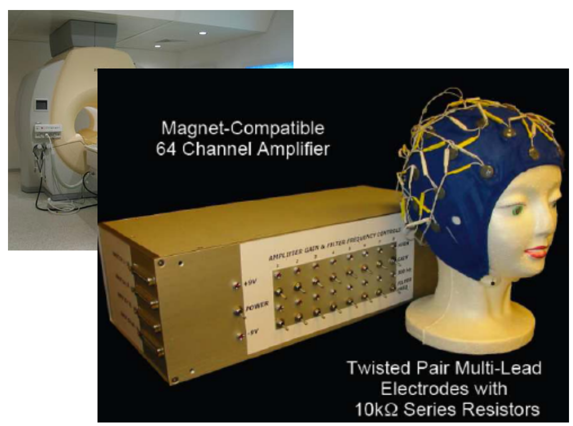


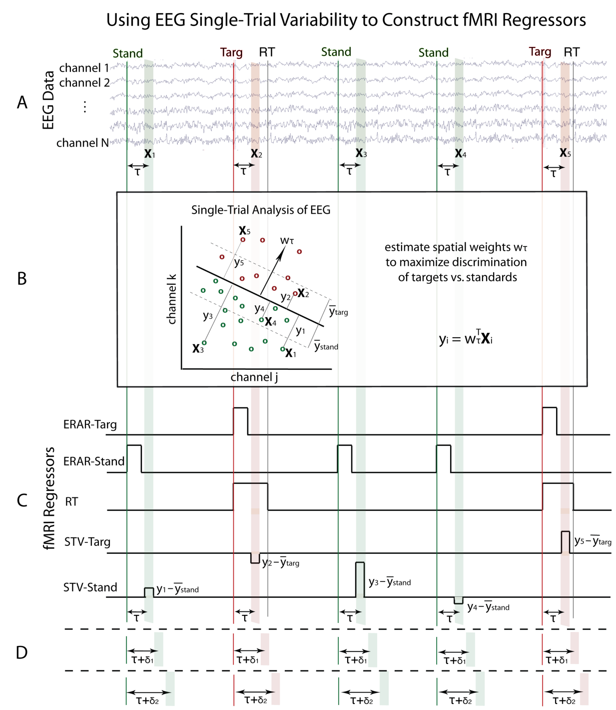
$$\mathbf{M_p u} = [\,\mathbf{1_p} \quad \mathbf{M_p}\,] \begin{bmatrix} e_p \\ \mathbf{n} \end{bmatrix}$$

← EEG+BCG

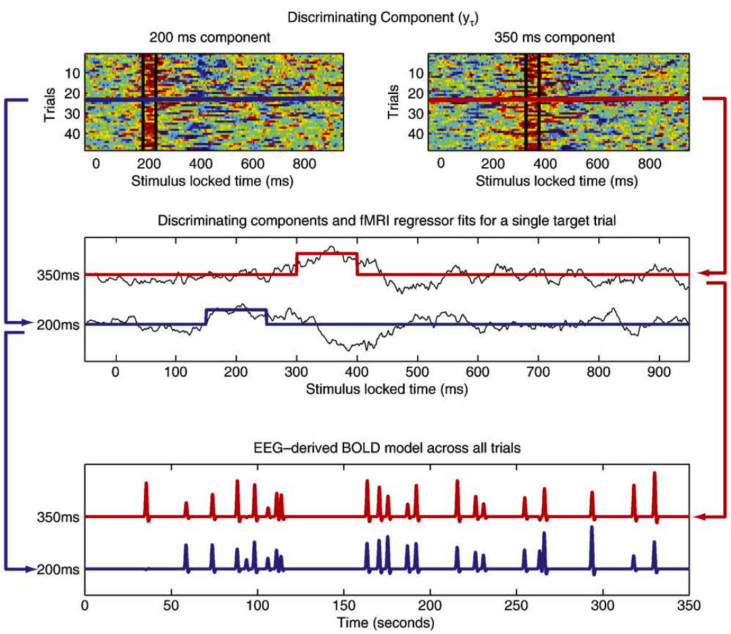
← BCG

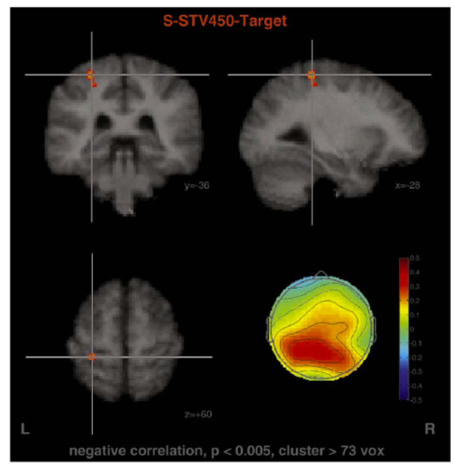


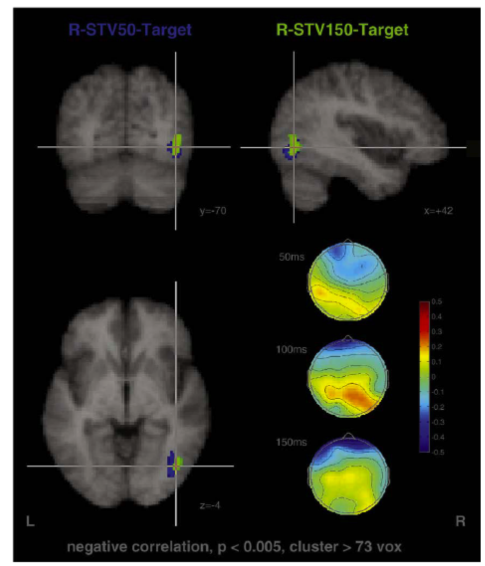




Observing latent trial-to-trial fluctuations of attention/ alertness/perceived-stimulus-salience



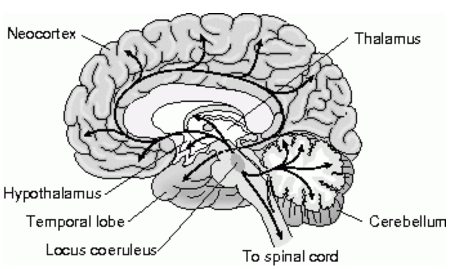


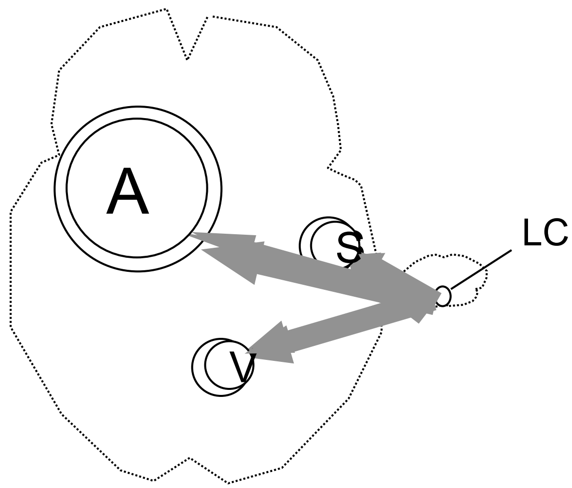


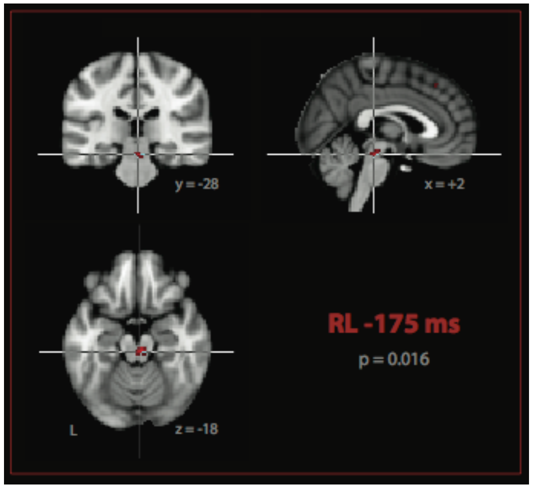
(Goldman et al., *Neuroimage* 2009)

Observing latent trial-to-trial fluctuations of attention/ alertness/perceived-stimulus-salience

Modulation of attention/alertness
via the locus coeruleus (LC)?

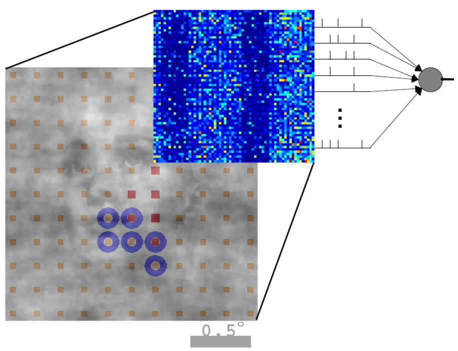


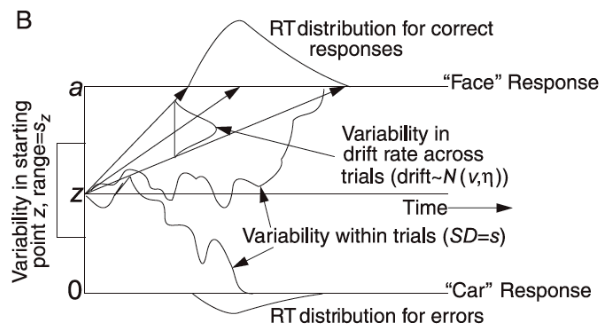


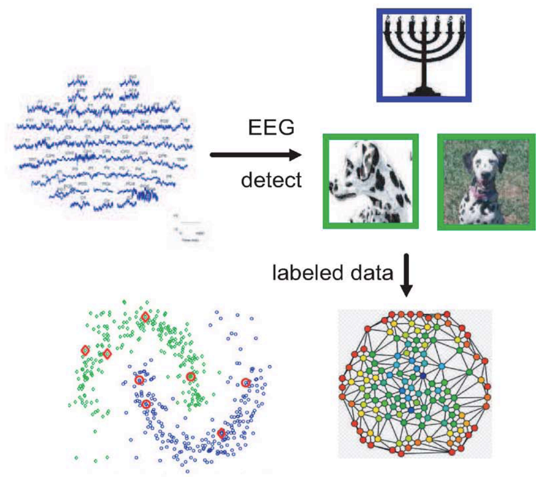


- Evidence that low freq LFPs (< 30Hz) have neg. corr. with BOLD (Mukamel et al, 2005)
- LC associated with P300 (Aston-Jones & Cohn, 2005)
- LC fires phasically close to response and appears to modulate decision/response and not sensory inputs (Clayton, et al. 2004)

Neurally-Informed Models of Decision Making







TAG
(Transductive Annotation by Graph)
Semi-supervised machine learning

level of abstraction

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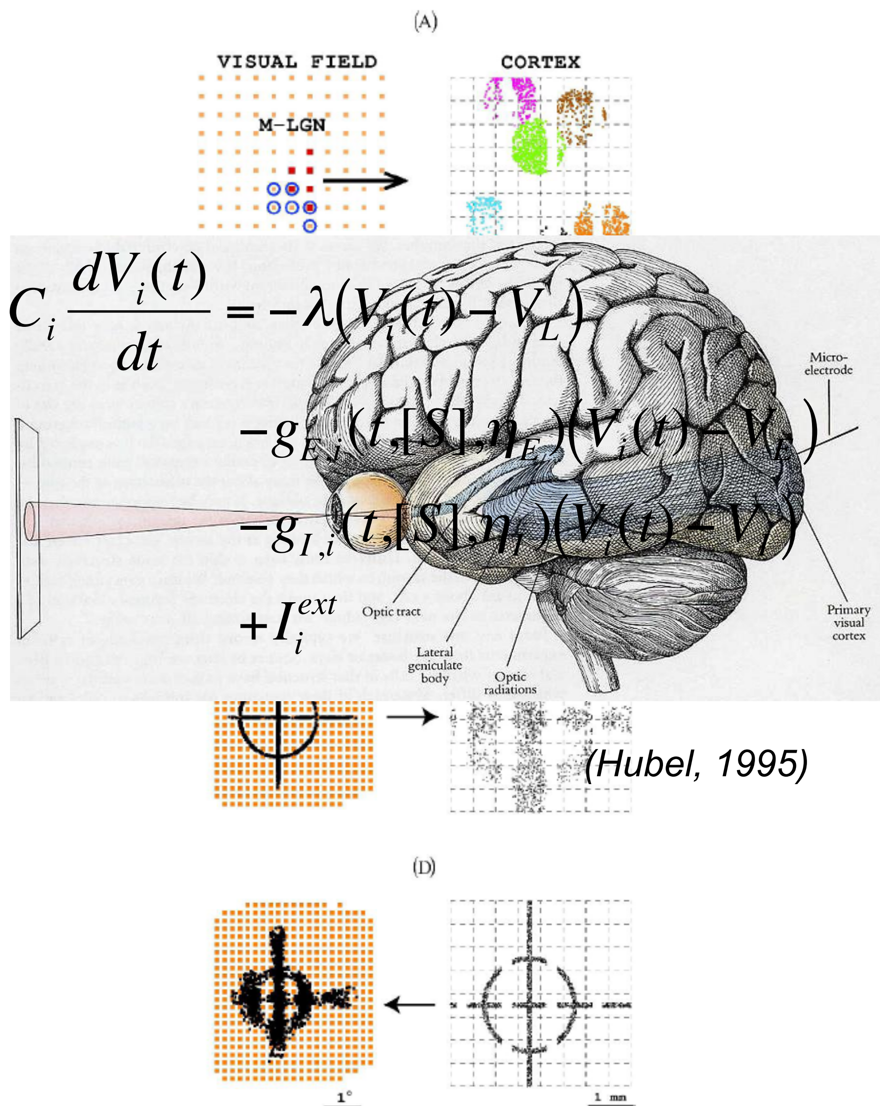
Model Summary

- Macaque V1, input layer (4Cα/β)
- 4 ocular dominance columns
- 64 orientation hypercolumns
- 16 mm^2 cortical area, 0-10^o eccentricity
- Approx. 65,000 neurons (integrate-and-fire) per configuration (α, β, 0^o , 10^o) = 260,000 neurons.
- Cell populations:
  - 75% excitatory cells
  - 25% inhibitory cells
  - 30% receive LGN input
  - 70% do not receive LGN input
- Anatomically realistic LGN input and retinotopic map
- Anatomically “correct” cortical length scales:
  - r_E^{axon}=200μm, r_I^{axon}=100μm
  - r_E^{dend}=50μm, r_I^{dend}=50μm
- First-order LGN temporal kernel
- Cortical time scales:
  - AMPA (5 msec)
  - NMDA (50 msec)
  - GABA (10; 100 msec)

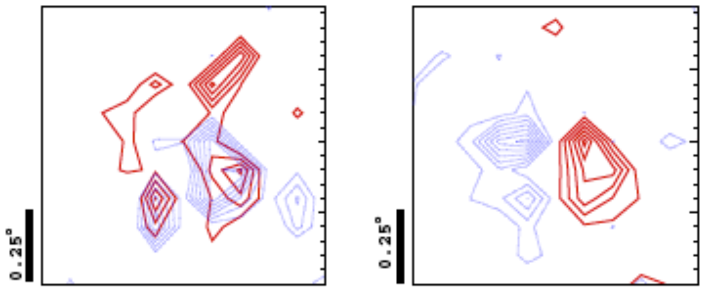
$$C_i \frac{dV_i(t)}{dt} = -\lambda(V_i(t) - V_L) - g_{E,i}(t,[S],\eta_E)(V_i(t) - V_E) - g_{I,i}(t,[S],\eta_I)(V_i(t) - V_I) + I_i^{ext}$$



(Hubel, 1995)

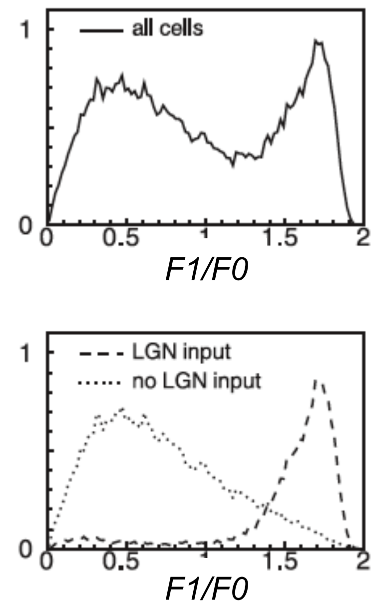
Model Has Realistic Response Properties

receptive fields

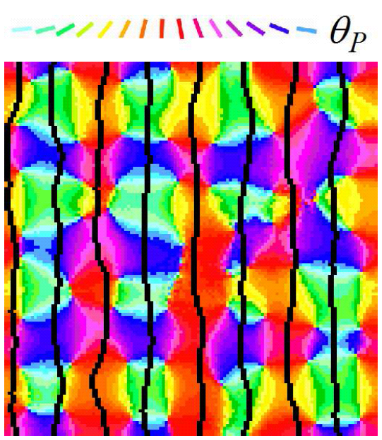


Wielaard and Sajda, 2006

characteristics of S & C cells



orientation pinwheels

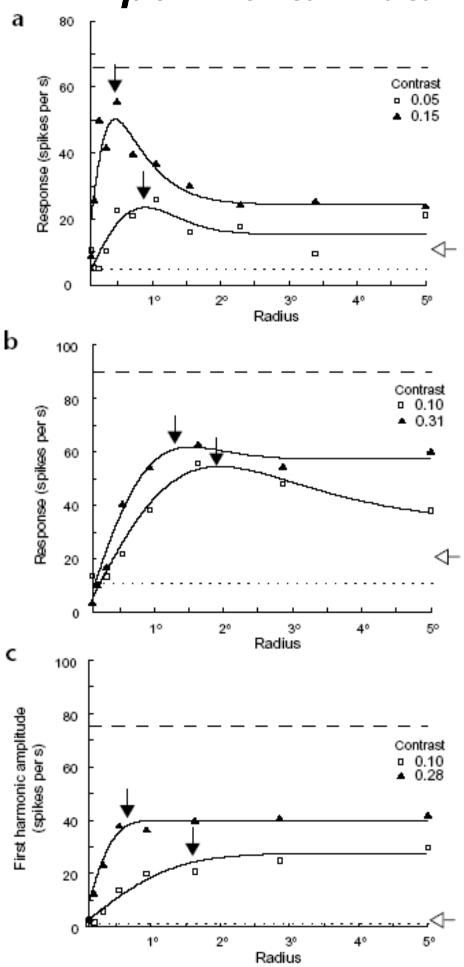


Wielaard and Sajda, 2003

Realistic Nonclassical Response Properties

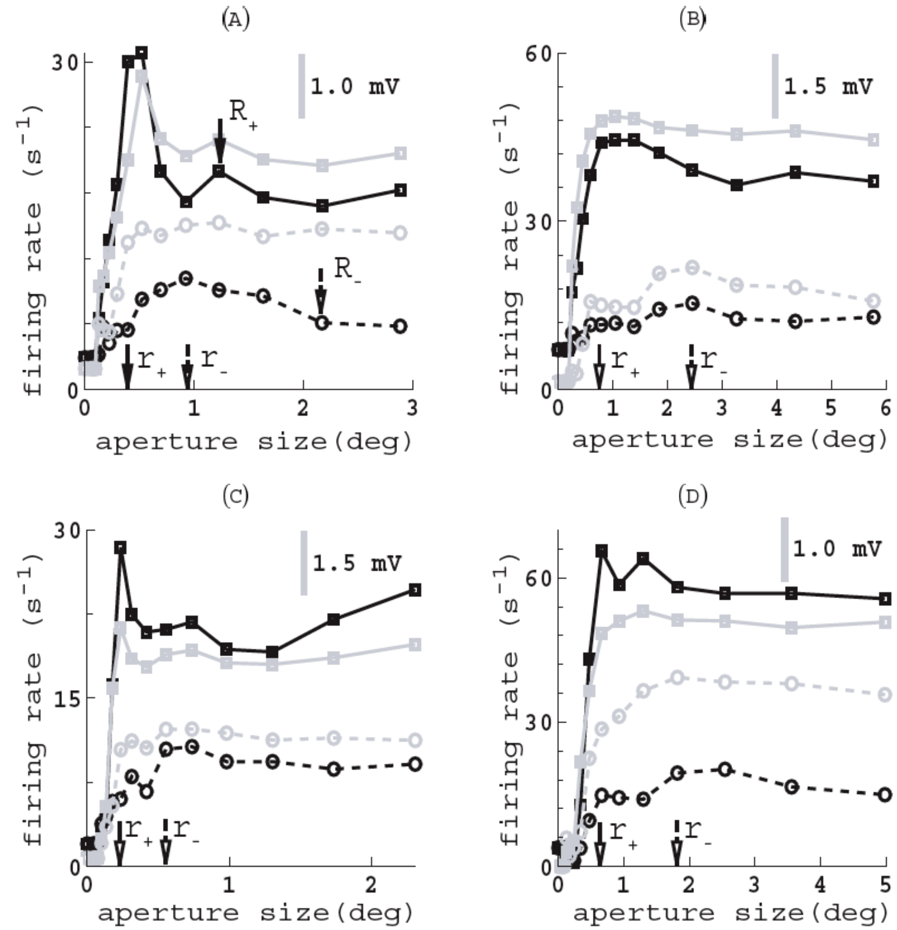
…suppression and RF shifts at high and low contrasts…

Experimental Data



from Sceniak et. al., 1999

Model



(Wielaard and Sajda, 2006)

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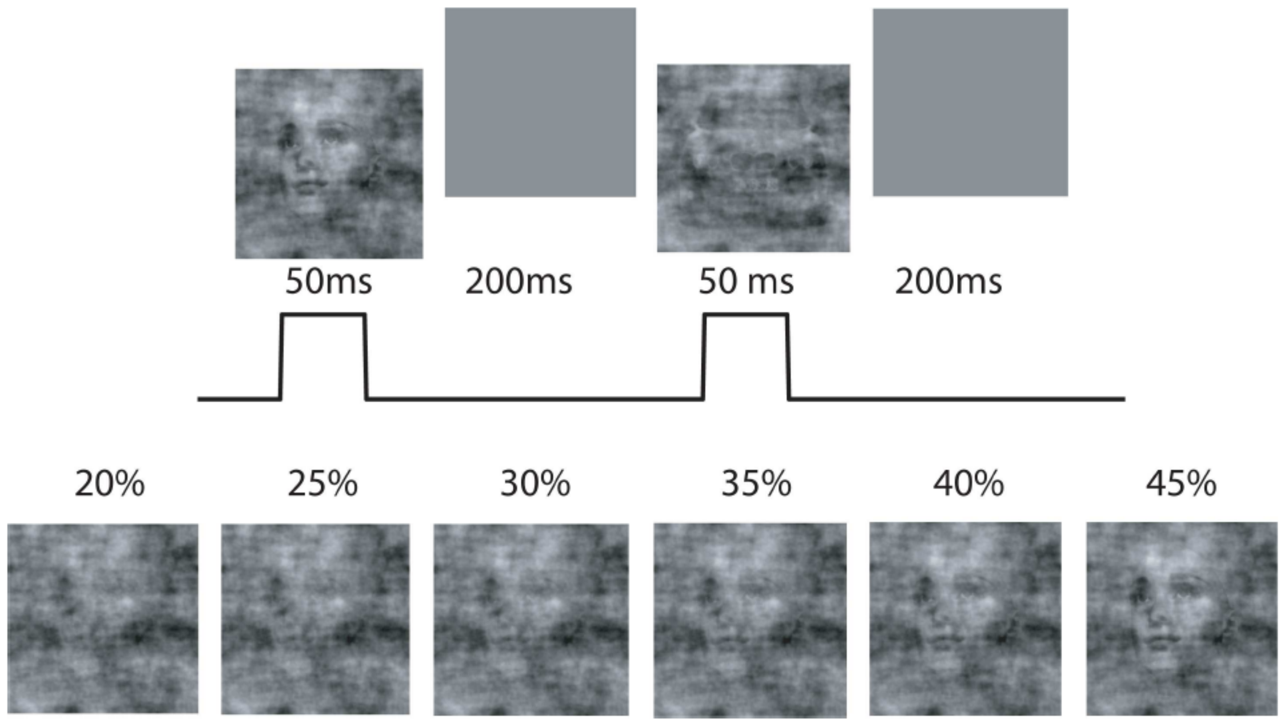
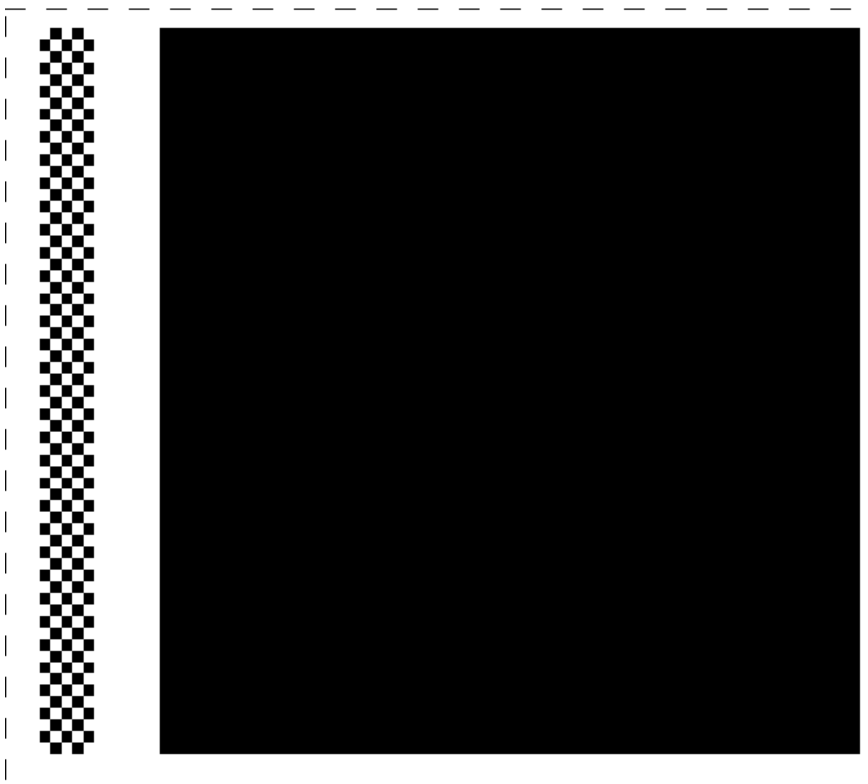
The Perceptual Decision Making Task

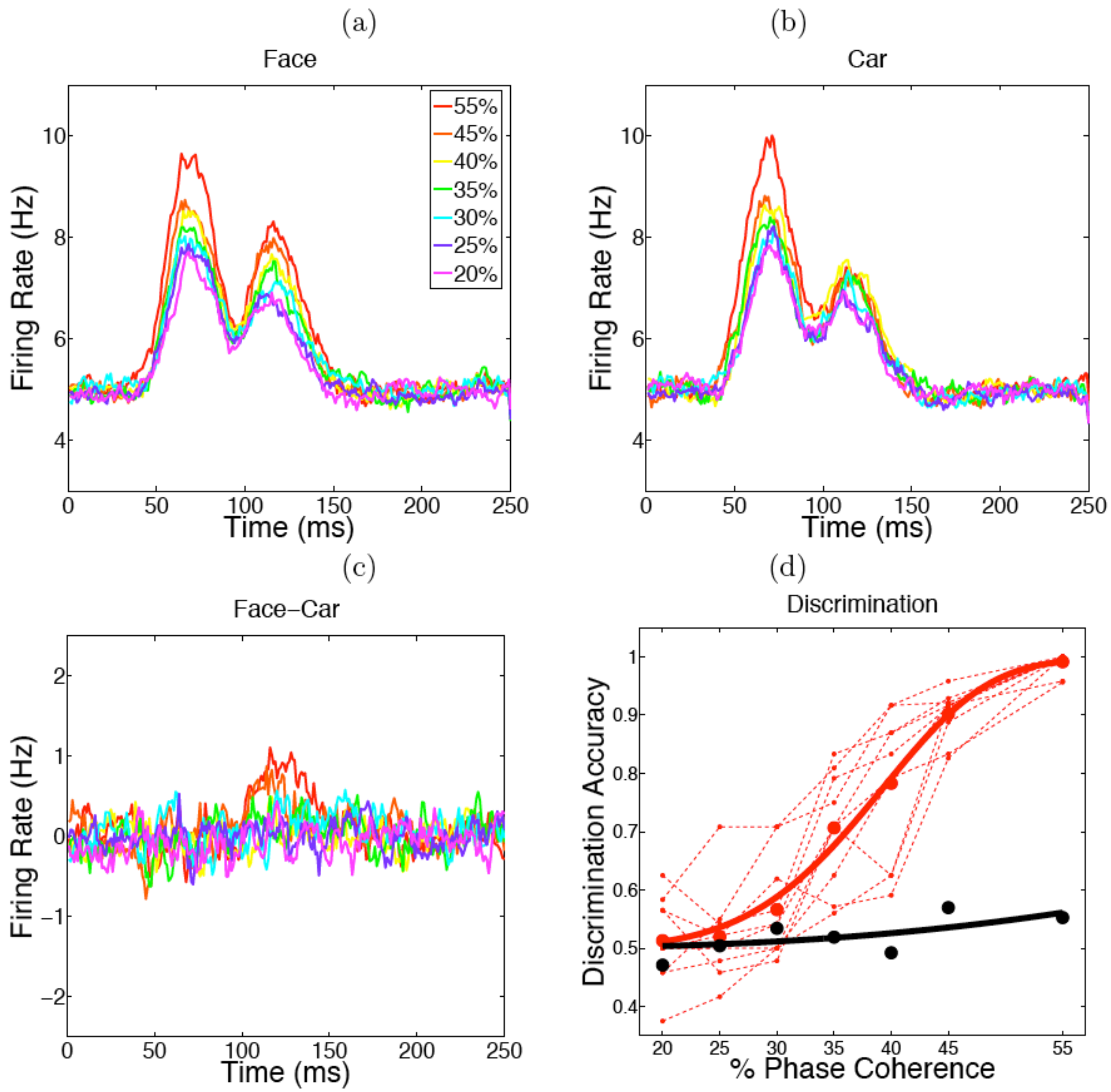


Mapping A Rapidly Flashed Static Scene into Spikes

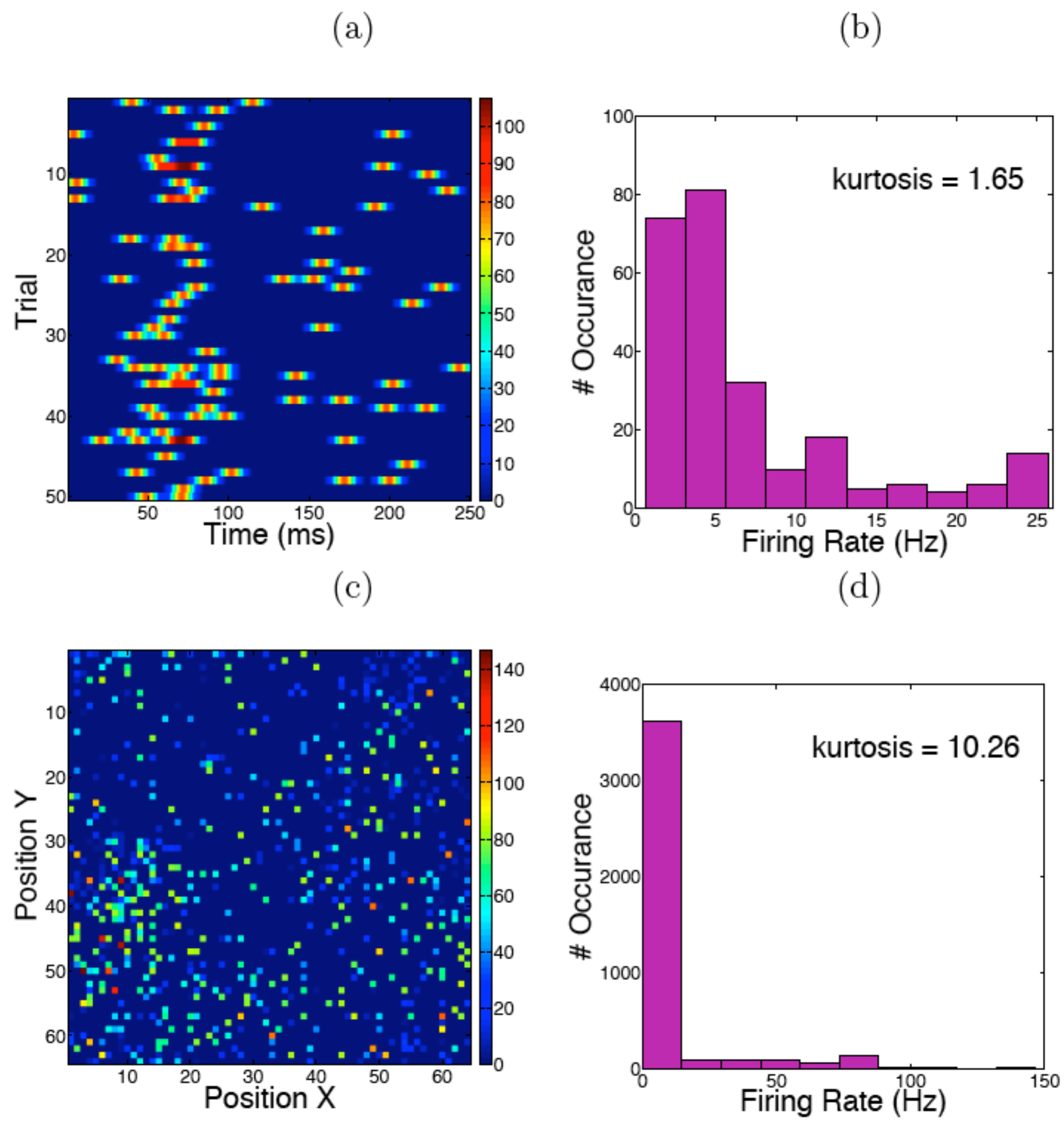


Face or Car ?

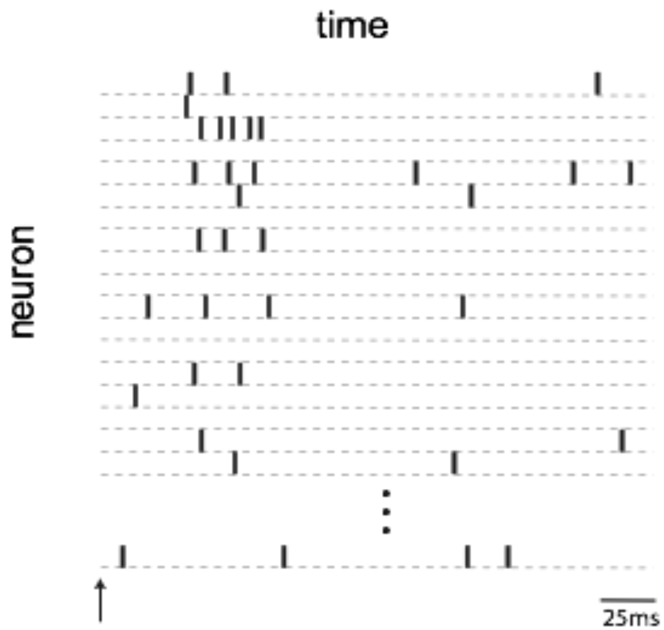
Using Population LFPs for Discrimination

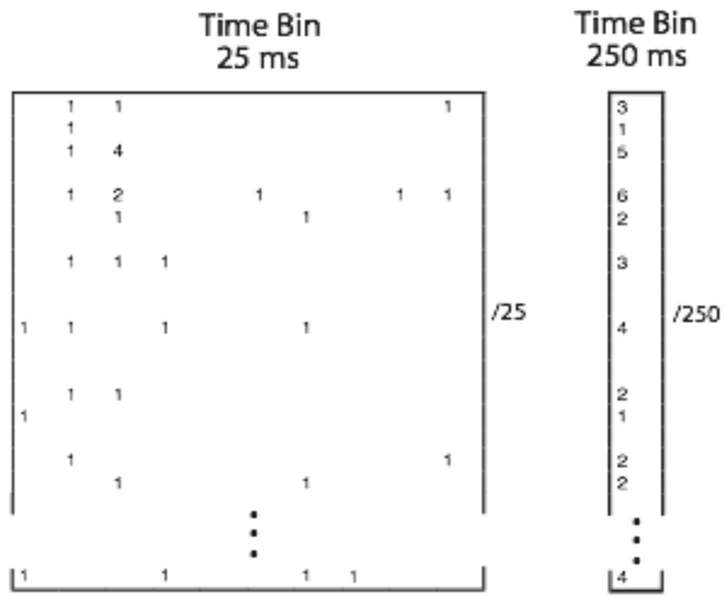


Sparseness of V1 Model Activity in Space and Time

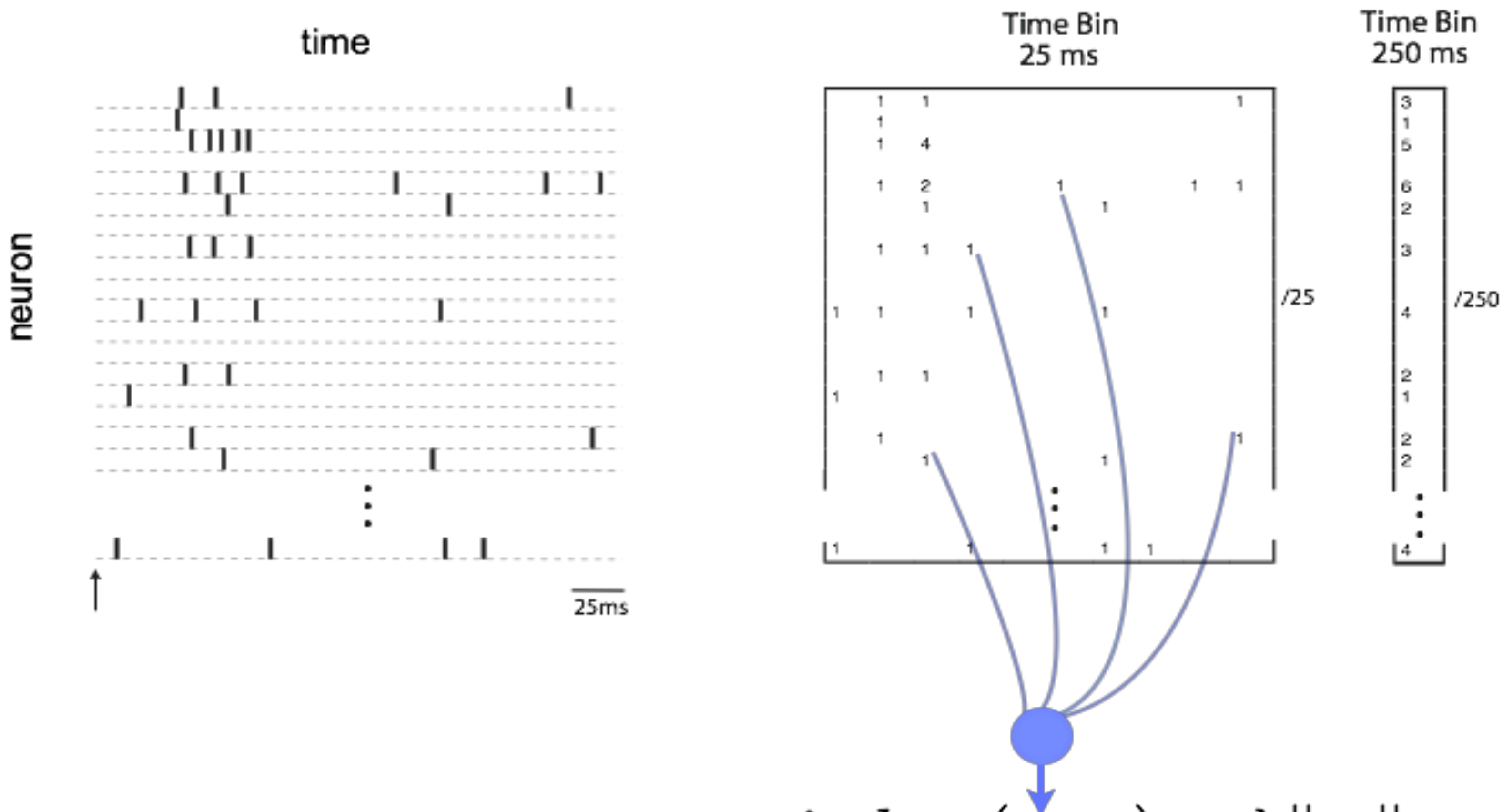


The Spike-based Feature Space or "Neural Word"





Decoding High-dimensional Spatio-temporal Dynamics



$$\arg\min_{w,v} l_{avg}(w,v) + \lambda \|w\|_1$$

Training and Testing Procedure

- Used 12 face images and 12 car images
- Divided into training and testing
  - 6 completely different faces and cars used to train and test
- Manipulated phase coherence of images at each of 7 different coherence levels.
- Images repeated 30 times resulting in a total of 5040 trials (2520 for training and 2520 for testing).
- Images covered approximately 4 degrees of visual angle for simulations.

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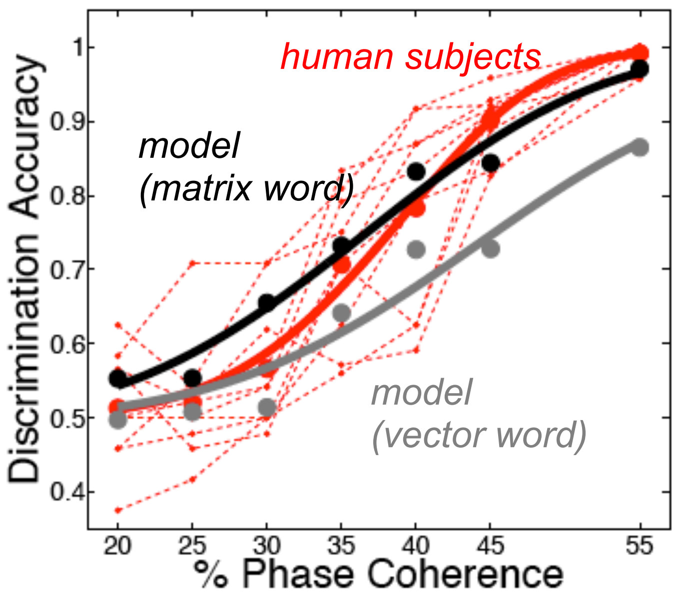
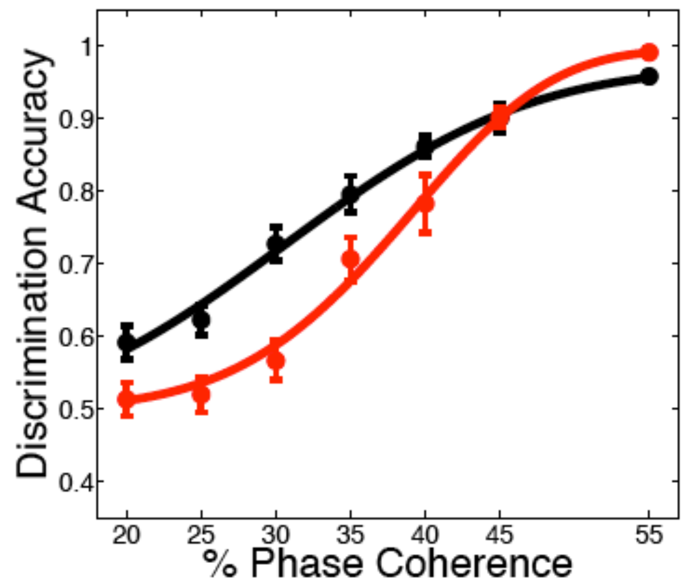
Discrimination Results

Neurometric curve NOT optimized to match psychometric curve!



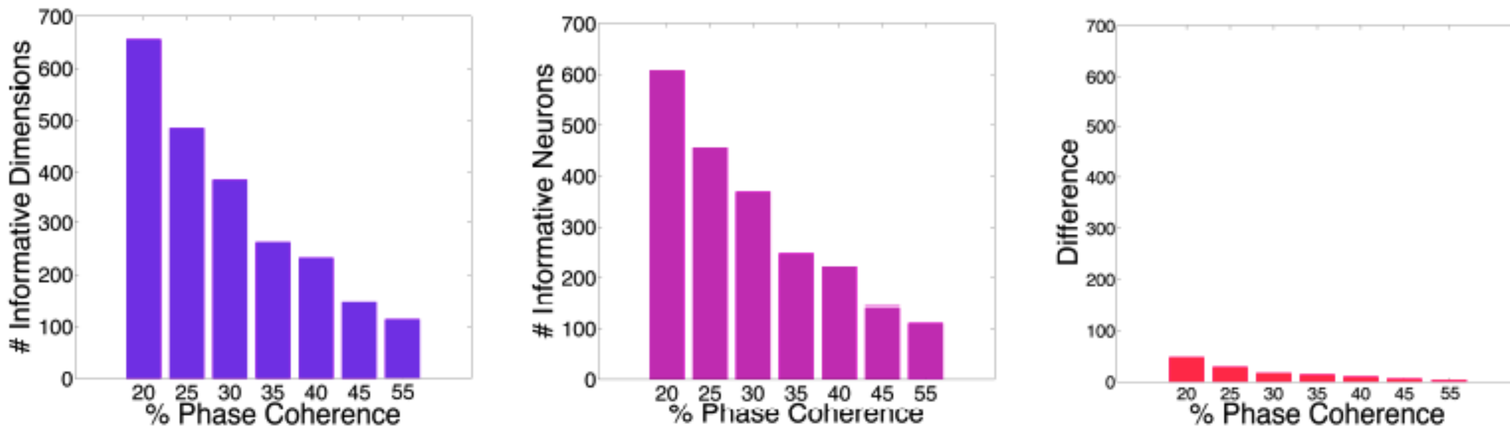
Average across 6 models and 10 subjects



Matrix word is better match to psychometric results.
High temporal precision (temporal code) is superior to rate code.

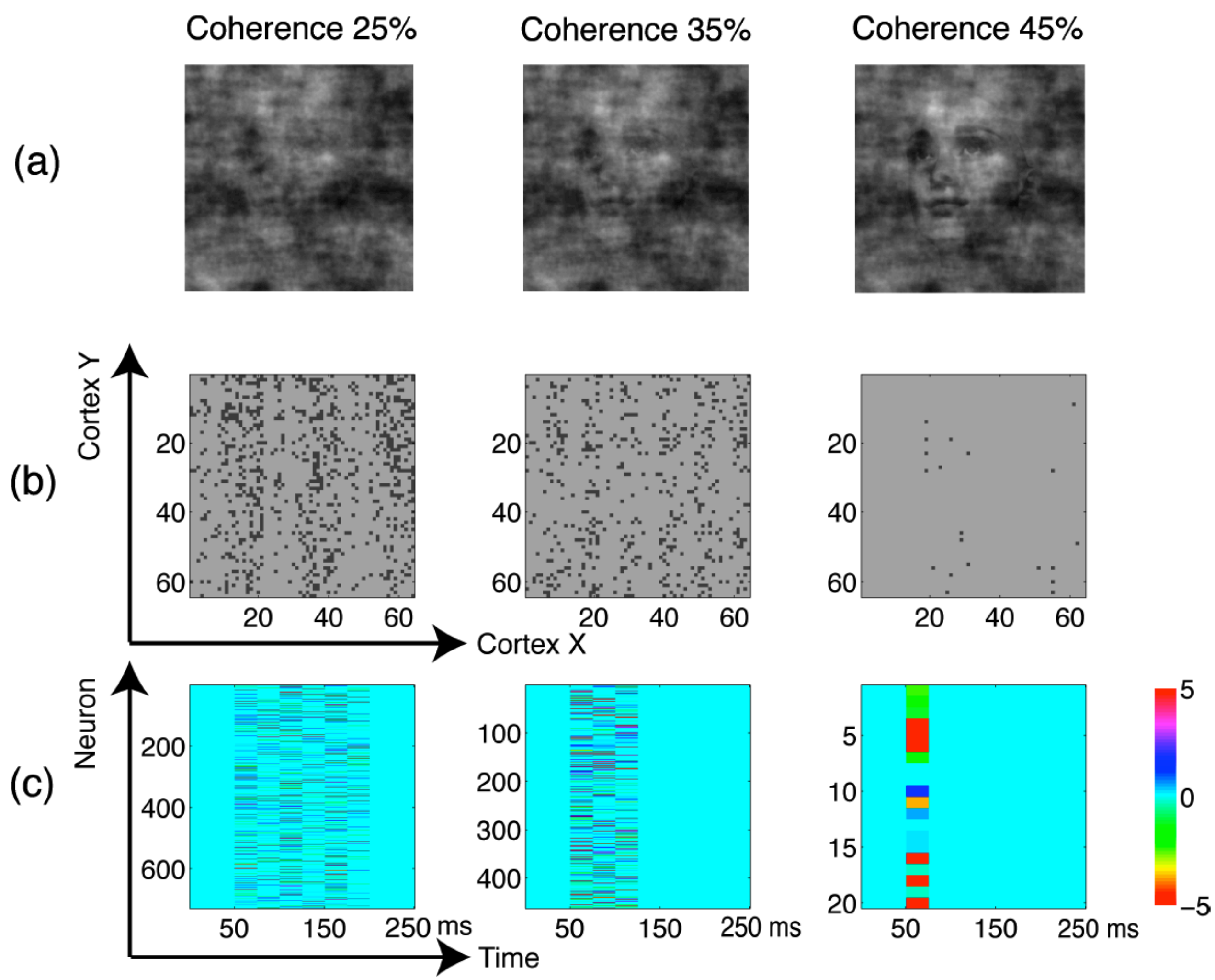
Analysis of Informative Dimensions

(a) # Informative Dimensions (b) # Informative Neurons (c) Difference

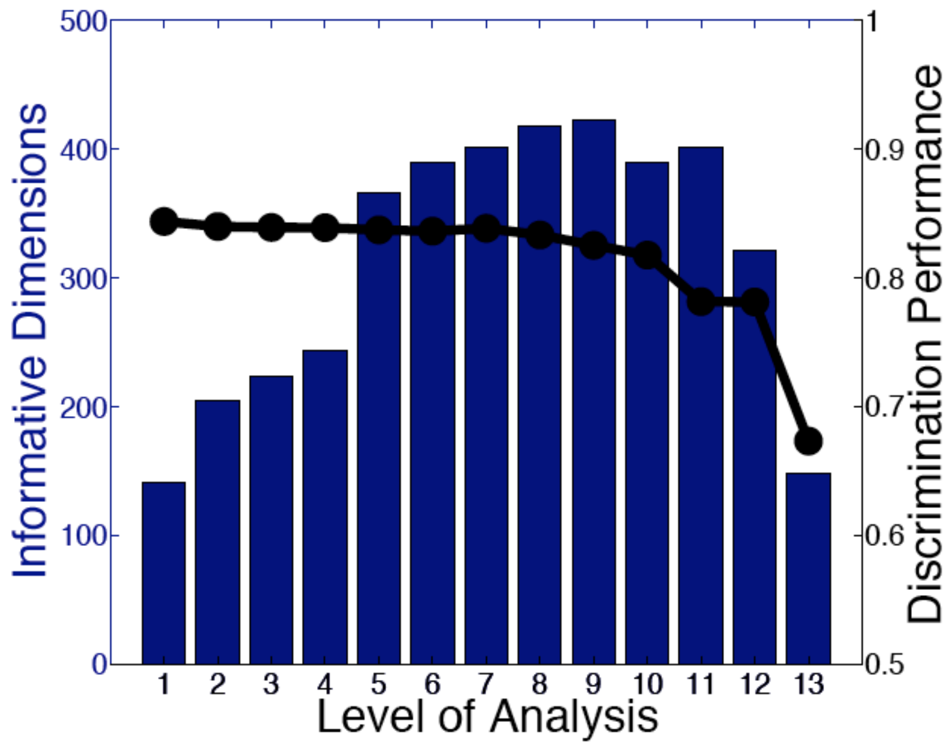


More neurons are recruited at lower coherences
Few neurons are utilized at more than one time bin

Selected Neurons



Uniqueness of Informative Dimensions



Where We Are:
Task: 3-Choice Perceptual Decision